THE NICKEL BULLETIN

A SUMMARY OF CURRENT INFORMATION ON NICKEL

FEBRUARY, 1951

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Developments in Metallurgy, 1929-1950

'Progress in the Metallurgical Industries, 1929-1950.' *Metallurgia*, 1950, vol. 42, Nov., pp. 275-352; Advt., p. 87.

This anniversary issue of *Metallurgia* contains a series of articles reviewing developments which have taken place in the metallurgical and allied industries since 1929, the year in which the journal was founded.

Subjects reviewed include the British iron and steel industry, special steels, carbon and low-alloy steels, steel castings, cast iron, refractories, the non-ferrous metals industry, copper, nickel and nickel alloys, tin and its alloys, the precious metals, zinc, aluminium, magnesium, heat-treatment equipment and technique, cold working of metals, powder metallurgy, metal finishing, iron-foundry technique, welding, and laboratory methods and apparatus.

Polishing and Buffing: Literature Review

J. H. LINDSAY: 'Polishing and Buffing: A Literature Review.' *Plating*, 1950, vol. 37, Nov., pp. 1143-8; Dec., pp. 1247-51.

The review, based on a *bibliography* of 60 references, covers the literature of 1944-1948.

B.S. Specifications for Creep- and Stress-Rupture-Testing

See abstract on p. 42.

Drawing Compounds for Stainless Steel

See abstract on p. 45.

Chemical Analysis of Nickel and Nickel Alloys

AMER. SOC. TESTING MATERIALS: '1950 Book of A.S.T.M. Methods for Chemical Analysis of Metals.' Published by the Society, 1950; 476 pp.

This revision contains all the current A.S.T.M. methods for chemical analysis of ferrous and non-ferrous metals and alloys, including spectrochemical procedures. It is essentially a part of the Book of A.S.T.M. Standards.

The scope is indicated below:—

I. General Recommended Practice (Apparatus, methods, etc.).
II. Sampling Methods.
III. Chemical Analysis of Ferrous Metals (Steel, cast iron, open-hearth iron, wrought iron, ferro-alloys).
IV. Chemical Analysis of Non-Ferrous Alloys (Nickel-chromium-iron alloys, nickel and nickel-copper alloys, copper and copper-base alloys, aluminium and aluminium-base alloys, magnesium and magnesium-base alloys, lead, tin, antimony and their alloys, silver solders, zinc and zinc-base alloys).
V. Spectrochemical Analysis Methods.

Effect of Nuclear Radiation on Nickel-containing Materials

D. S. BILLINGTON and S. SIEGEL: 'Effect of Nuclear Radiation on Metal.' *Metal Progress*, 1950, vol. 58, Dec., pp. 847-52.

Intense radiation, as existing within a uranium reactor, may be expected to disrupt the crystalline structure of metals exposed to it. This article presents a theoretical discussion of this subject (by members of the staff of Oak Ridge National Laboratory), and reports experiments made to check the assumptions made.

The experimental data were obtained in two ways:—

(1) The properties of the metals to be exposed were measured before irradiation; samples were then exposed in a reactor, under known conditions of neutron flux and temperature, and finally, the properties were re-measured after removal from the reactor.

(2) The properties of the materials were measured while the sample was still in the reactor. Such measurements have at present been restricted to those in which the information can be brought out on electrical leads, and have been confined to measurements of electrical and thermal resistivity. The Oak Ridge group is, however, developing methods for measuring elastic modulus, Hall coefficient, and creep, while samples are in a reactor.

The materials exposed comprised aluminium, copper, copper-gold alloy (Cu_3Au), copper-beryllium alloys, stainless steels (Types 309, 316 and 347), Monel, S.A.E. 4340 nickel - chromium - molybdenum steel, brass, and silicon bronze.

The results show that exposure of metals to the energetic radiations in a nuclear reactor produce changes in macroscopic properties. These changes depend markedly on the nature of the metal, its metallurgical condition and the duration of the exposure.

NICKEL

Thermal Polishing and Etching of Nickel

A. G. METCALFE and M. J. OLNEY: 'Thermal Polishing and Etching.' *Metal Progress*, 1950, vol. 58, Nov., pp. 733-4.

Commenting on letter from G. W. WENSCH (*ibid.*, 1950, vol. 57, p. 488; *Nickel Bulletin*, 1950, vol. 23, No. 6, p. 102) describing phenomena observed on the surface of nickel specimens after long times of annealing in sealed evacuated tubes, the writers point out that under the conditions described re-deposition of nickel on the specimen from the vapour phase would be expected, and that this may well contribute to the polishing effect observed. Metcalfe and Olney are of the opinion, however, that surface migration is a more potent mechanism, and that this will act in such a way that the free energy of the surface is reduced, as will occur if the surface area is diminished by removal of scratches and other irregularities.

Attention is directed to earlier work on thermal etching and polishing, and it is stated that the writers are using this technique, in the laboratories of the University of Cambridge, for examination of metals at elevated temperatures, employing a reflecting microscope. Although the equilibrium surface so produced is not found to be so smooth as a mechanically polished surface, the irregularities observed are intrinsically of interest, as related to the internal structure of the metal. The writers confirm Wensch's observations on nickel, supplying a photomicrograph of the equilibrium surface of a nickel rod heated under slight compression in vacuo to 1410°C. Comment is made on the effects of viscous flow and grain growth exhibited in the photograph.

Composition of Raney Nickel Catalyst

V. N. IPATIEFF and H. PINES: 'Composition of W-6 Raney Nickel Catalyst.' *Jnl. Amer. Chemical Soc.*, 1950, vol. 72, Nov., pp. 5320-1.

The authors report a precise determination of the composition of this catalyst, prepared by the method of ADKINS and BILLICA (*ibid.*, 1948, vol. 70, p. 695: *Nickel Bulletin*, 1948, vol. 21, No. 4, p. 49).

The following results are given:—

	Sample 1	*Sample* 2	*Average*
Nickel	77·0	76·95	76·97
Aluminium ..	12·75	12·69	12·72
Sodium.. ..	0·15	0·15	0·15
Total	89·90	89·79	89·84

The following percentage composition is derived from these figures: metallic nickel 76·97, aluminium oxide 21·13, sodium aluminate 0·54, metallic aluminium 1·36.

The findings vary from those reported by Adkins and Billica, who reported the composition as about 11 per cent. aluminium, remainder nickel. Experiments confirming the presence of alumina in the catalyst are described. It is suggested that the high activity of Raney nickel is due not only to the large surface area of the catalyst, but also to the presence of aluminium oxide: reference is made to earlier work, by the senior author, which demonstrated the pronounced effect of alumina on a nickel catalyst (*Berichte*, 1912, vol. 45, p. 3205).

Raney Nickel Catalyst: Preparation, Characteristics, Uses

S. H. TUCKER: 'Catalytic Hydrogenation Using Raney Nickel.' *Jnl. Chemical Education*, 1950, vol. 27, Sept., pp. 489-93.

A good summary of information, prepared primarily for the instruction of students. The introduction of this form of catalyst, in 1927, by Murray Raney, is recorded, and the work of later investigators is reviewed, with particular reference to attempts which have been made to improve the activity of the catalyst by modifications in method of production. Practical notes on preparation of the catalyst, measuring, and use are given in some detail, hydrogenation apparatus is illustrated, and typical examples of catalytic hydrogenation which can be carried out with Raney nickel are described.

Influence of Silicon Dioxide in Nickel Catalysts

J. J. B. VAN EIJK VAN VOORTHUIJSEN and P. FRANZEN: 'The Influence of Silicon Dioxide on the Activity of Nickel Catalysts.' *Recueil des Travaux Chimiques*, 1950, vol. 69, pp. 666-7; *Chem. Abs.*, 1950, vol. 44, p. 10473.

'Under appropriate conditions $Ni(OH)_2$ and SiO_2 gel can form two compounds: $Ni_3(OH)_4Si_2O_5$ (nickel antigorite) and $Ni_3(OH)_2(Si_2O_5)_2$ (nickel montmorillonite). These two compounds, together with $Ni(OH)_2$, are present in the pre-reduction stage of nickel-on-silicon dioxide catalysts, depending on the nickel: silicon ratio. Their properties are a determining factor for the activity of the catalysts prepared from them by reduction.'

'Deuterized' Raney Nickel Catalyst

D. K. FUKUSHIMA, S. LIEBERMAN and B. PRAETZ: 'Preparation of Deuterated Steroids.' *Jnl. Amer. Chemical Soc.*, 1950, vol. 72, Nov., pp. 5205-11.

In recent years there has been increasing recognition of the important rôle played by steroid hormones in the functioning and regulation of various physiological processes. On account of the success of the isotope tracing technique, in clarifying other biochemical and physiological problems, there is also great interest in this subject in connexion with steroid biochemistry.

This paper describes two methods for the incorporation of deuterium atoms on C_7 of Δ^5-unsaturated steroids. The methods are general and can be applied to a variety of steroid hormones or related compounds, and have certain other advantages which are discussed by the authors.

One of the procedures developed consisted in the bromination of Δ^5-unsaturated steroids with N-bromosuccinimide, followed by catalytic replacement of the 7-bromo group of the product with deuterium. The deuterium atom in 7-*d*-Δ^5-steroids prepared in this manner was shown to be stably bound. The other procedure involved the desulphurization of suitable steroid mercaptols with 'deuterized' Raney nickel, affording d_2 steroids. Preparation of the deuterized nickel catalyst and its use are described in detail.

Chemical Reactions of Nickel Carbonyl

E. D. BERGMANN and E. ZIMKIN: 'The Reaction of Nickel Carbonyl with Ethynyldimethylcarbinol and *iso*Propenylacetylene.' *Jnl. Chemical Soc.*, 1950, Dec., pp. 3455-7.

'It is shown that the carboxylation of the two compounds takes place at the terminal acetylenic carbon atoms. From ethynyldimethylcarbinol, primarily butyl 4-hydroxy-4-methylpent-2-enoate* is formed; the primary product from *iso*propenylacetylene dimerises to (probably) 1-methyl-5-*iso*propenyl*cyclo*hexene-3: 4-dicarboxylic acid.'

Thermodynamic Data on Nickel Chloride

H. VILLA: 'Thermodynamic Data of the Metallic Chlorides.' *Jnl. Soc. Chemical Industry*, 1950, vol. 69, *Suppl. Issue No. 1*, 1950, pp. S9-S18.

Free energies of formation of 33 inorganic chlorides, between room temperature and 1800°C., are calculated from thermodynamic data and equilibrium measurements. Results are expressed in equations of two and three terms, and are plotted in a diagram vs. temperature. The sources of the data used in calculation are discussed, and limits of accuracy are ascribed to each equation.

The review includes data on the chlorides of nickel, cobalt and iron.

Thermal Stability of Nickel Carbide

L. J. E. HOFER, E. M. COHN and W. C. PEEBLES: 'Isothermal Decomposition of Nickel Carbide.' *Jnl. Physical and Colloid Chemistry*, 1950, vol. 54, Nov., pp. 1161-9.

Report of study made to gain closer insight into the problem of the formation of free carbon during hydrocarbon synthesis by the Fischer-Tropsch process, a side reaction which leads to plugging of fixed-bed reactors, or disintegration and loss of catalyst in fluidized-bed converters, and to decrease or total loss of catalytic activity.

Thermal stability of Ni_3C was studied magnetically and by X-ray diffraction, between 320° and 355°C., on a fully carburized, and on a 95 per cent. carburized sample.

It was found that an induction period precedes decomposition, and that this period is analogous to that found in the decomposition of austenite. There is no detectable change in the carbide during the induction period.

The carbide decomposed into free metal and free carbon without intermediate formation of a lower carbide.

Detection of Nickel by the Dimethylglyoxime Test

A. KUTZELNIGG: 'The Reactivity of Metal Reagents under Unusual Conditions.' *Werkstoffe und Korrosion*, 1950, vol. 1, Dec., p. 509.

The author claims that the nickel dimethylglyoxime reaction, for which aqueous solutions have always been considered necessary, can be carried out in a simpler manner. Water-soluble and -insoluble compounds of nickel, e.g., nickel carbonate, or metallic nickel, react on rubbing with solid diacetyldioxime, giving a red coloration. The red colour can also be obtained by dry heating of nickel compounds or metallic nickel in contact with diacetyldioxime.

Diacetyldioxime vapour reacts, under suitable conditions, after 24 hours in contact with nickel at normal temperature, and at 100°C. the reaction takes place in a few minutes.

Similarly, cadmium chloride reacts on rubbing with diphenylcarbazone, copper with diethyldithiocarbamate, and zinc with diphenyldithiocarbazone.

Chemical Analysis of Nickel

See abstract on p. 28.

Diffusion of Copper in Nickel

R. S. BARNES: 'Diffusion of Copper along the Grain Boundaries of Nickel.' *Nature*, 1950, vol. 166, Dec. 16, pp. 1032-3.

A brief résumé is made of earlier literature on preferential diffusion along grain boundaries in various metals, and experiments are reported indicating that copper diffuses preferentially along the grain boundaries of nickel. Photomicrographs of copper-nickel sandwiches (after annealing at 1,000°C. for 36 hours) illustrate the observations made.

Production of Edison Alkaline Accumulators

G. E. STRINGFELLOW: 'Producing Storage Battery Parts with Special Equipment.' *Machinery* (*N.Y.*), 1950, vol. 57, Dec., pp. 172-8.

Nickel-iron alkaline accumulators, now made in a wide range of types and sizes, are in general use as a source of operating power for equipment such as industrial trucks, mine locomotives, and shuttle cars, and as a source of standby power for railway passenger car-lighting and air-conditioning, signals, and other applications in which long life and dependability are essential.

This article describes some of the major operations involved in production of batteries of this type, at the West Orange works of Thomas A. Edison, Inc. The perforated steel tubes which hold the layers of nickel hydrate and nickel flake are cold-rolled on a Steckel mill, and the reels of strip so produced are perforated by feeding between circular male and female dies which make 550 perforations to the square inch. Small burrs formed in this operation are removed by

*Geneva numbering.

grinding, the strip is then cleaned, and is passed to the nickel-plating plant, in which it is continuously plated, while winding round rollers in the tanks. In order to ensure the complete adhesion required, the strip is annealed, after plating, in an atmosphere of hydrogen. The bonding of the nickel to the steel resulting from this treatment is so firm that the strip can be twisted and folded without separation of the nickel from the underlying steel. The pockets which contain the negative material (finely divided iron oxide) are processed in a closely similar manner, except that 1900 perforations per square inch are formed.

The next operation is the forming of strip into tubes, which is performed in automatic machines specially designed for this work; illustrations are given in the text. The tubes are then placed in machines for packing. Nickel hydrate flows from a hopper on one side of the machine, while a hopper, on the other side, provides a flow of nickel flake; the flow from each track is automatically stopped at intervals, to provide for alternation of the layers of nickel hydrate and flake.

After inspection, the tubes are capped, reinforcing rings are placed on them, and the tube ends are closed by crimping.

Pockets for the negative material are formed and loaded in a specially designed machine (also illustrated in the paper), and hydraulic presses are used to press the pockets into grid frames and form a lock.

The cold-rolled steel cell-containers are made from 20-gauge (0·036 in.) stock, are curled over the edges in a press, and the parts are nickel plated. The edges of the container are joined by automatic seam-welding; the methods used are described and illustrated, and notes are added on another welding operation which uses fixtures of a specialized type, in spot welding of suspension bosses to the containers.

Grid frames, in which tubes and pockets are to be assembled by the methods described, are blanked from coils of cold-rolled steel, in a punch press, using a compound die.

Production of the pure nickel flake begins with a series of plating operations, using automatic equipment. The machines used have ten cylindrical plating vats on each side of a water washing unit. An overhead crane carries ten steel cylinders from one set of vats, in which they have been copper-plated, to the water wash, and then to the opposite set of vats, in which they are nickel-plated. They are then returned to the water wash and back again to the first vats, repeating the whole cycle of operations (copper-plating to nickel-plating) until the cylinders have been treated 131 times. Approximately $3\frac{1}{2}$ hours is required to complete a full cycle, after which the sheets are stripped from the cylinders and are slit into $\frac{1}{16}$-in. wide strips, which are subsequently passed through a machine to cut them to $\frac{1}{16}$-in. squares. These squares are placed in a weak acid solution, which dissolves the copper without affecting the nickel.

Separation of the nickel flakes from this solution is accomplished in a centrifuge, after which they are washed in water, dried, and screened for size. Laboratory samples are taken for test prior to release of the batches.

ELECTRODEPOSITION AND OTHER COATING METHODS

Electrodeposition of Nickel from Fluoborate Solutions

C. STRUYK and A. E. CARLSON: 'Nickel Plating from Fluoborate Solutions.' *Plating*, 1950, vol. 37, Dec., pp. 1242-4, 1263-4.

The investigations reported provide information supplementary to that given by ROEHL and WESLEY (*ibid.*, 1950, vol. 37, pp. 142-6, 171; *Nickel Bulletin*, 1950, vol. 23, No. 4, p. 66, and No. 7, p. 128).

The investigation was made in connexion with the use of nickel-fluoborate solutions for barrel plating and production of stereotypes. The baths shown in the table below are typical of the solutions used, but it is emphasized that, due to high solubility, the nickel-fluoborate system is very versatile and that a wide range of bath compositions can successfully be used, to meet a variety of practical working requirements.

Typical Plating Baths

	Low		Medium		High*	
	g./L.	oz./gal.	g./L.	oz./gal.	g./L.	oz./gal.
Nickel fluoborate, $Ni(BF_4)_2$	220	29·5	300	40	440	59
Nickel, Ni	55	7·4	75	10	110	14·8
Free fluoborate acid, HBF_4	4-38	0·5-5	4-38	0·5-5	4-38	0·5-5
Free boric acid, H_3BO_3 ..	30	4	30	4	30	4
pH (colorimetric)	2·0-3·5		2·0-3·5		2·0-3·5	
Temperature °F. ..	100-170		100-170		100-170	
°C. ..	37·7-76		37·7-76		37·7-76	

* Nickel concentrations as high as 175 g./L. may be used.

The authors present a comparison of deposits prepared from such baths, with deposits made from typical Watts and all-chloride solutions. The investigation included study of buffer characteristics, effects of variation of composition in the baths, throwing power, the mechanical properties and hardness of the deposits, and the stress present in them, and the influence of impurities (copper, zinc, lead and iron).

From the results obtained (reported in detail in the original), the following conclusions are drawn:—

'The control of the fluoborate bath is simple, involving only a gravity reading and a pH determination.

'The deposits are light in colour, smooth, and exhibit some lustre, or sheen, over a wide range of current densities.

'The fluoborate solution is buffered more highly than the sulfate or chloride baths. This means that the bath is extremely resistant to pH changes and requires less attention for control and adjustment.

'Anode performance is excellent over a wide range of operating conditions.

'The fluoborate solution has a relatively high tolerance for metallic impurities, apparently higher than the chloride-sulfate nickel solution.

'The conductivity of the solution is high; about twice that of the Watts-type nickel baths and approximately equal to that of the all-chloride baths.

'Nickel fluoborate has high solubility, allowing the use of bath concentrations far above those possible with sulfates or chlorides. This is very advantageous where extremely high plating rates are desired.

'The bath is stable and substantially free from sludge, thus insuring better quality deposits.

'The internal stress in deposits from the fluoborate solution is lower than in those from Watts-type nickel baths and much less than in those produced from chloride solutions.

'The throwing power of the fluoborate bath is improved by additions of ammonium fluoborate. Such additions are not accompanied by formation of relatively poorly soluble double salts, as in the case of the sulfate and chloride systems.'

Consideration was also given to the possible use of nickel-fluoborate baths in bright plating. The following summary is made of conclusions which can be drawn from the preliminary work done in this connexion:—

'In a nickel-fluoborate bath, formaldehyde exerts a profound brightening effect, whereas the effect of nickel formate is slight, and small additions of cobalt are apparently without effect. The primary organic brighteners all exert a profound brightening effect when used in the nickel-fluoborate bath, without the deposits attaining the degree of brightness required by commercial bright nickels. Full brightness resulting from the further addition of brighteners of the second class has not been fully explored.

'In addition to bright-nickel plating, processes for plating semibright and easily buffed nickel have been developed in recent years. The high conductivity and rapid-plating characteristics of the nickel-fluoborate system offer interesting possibilities for further development in this direction.'

An appendix to the paper gives details of method of preparation of nickel-fluoborate plating baths.

Grain Size and Hardness of Bright Nickel Deposits

H. J. READ and R. WEIL: 'Grain Size and Hardness of Nickel Plate as Related to Brightness.' *Plating*, 1950, vol. 37, Dec., pp. 1257-61.

An earlier paper (*ibid.*, 1949, vol. 36, pp. 355-61; *Nickel Bulletin*, 1949, vol. 22, No. 5, p. 76) reported studies showing that there is no relationship between preferred orientation and brightness in nickel deposits. In this later report an account is given of further work, comprising investigation of the grain size and hardness of a group of specimens prepared from solutions containing a variety of brightening agents. The brighteners used (in various concentrations) were of the following types: saccharin, naphthalene disulphonic acid (1-5 and 2-7), *p*-toluene sulphonamide, *m*-benzene disulphonic acid, zinc+naphthalene disulphonic acid, chloral hydrate+1-5 naphthalene disulphonic acid, formaldehyde+1-6 naphthalene disulphonic acid, nickel formate+*p*-toluene sulphonamide, chloral hydrate+*p*-toluene sulphonamide and formaldehyde+*p*-toluene sulphonamide.

The basis nickel bath to which these additions were made contained 42 oz./gal. single nickel salts, $NiSO_4.6H_2O$; 6 oz./gal. nickel chloride, $NiCl_2.6H_2O$; 5 oz./gal. boric acid, H_3BO_3. Plating conditions were: pH 4·0; temperature 140°F. (60°C.); current density 50 amp./sq. ft. The panels plated were electropolished bumper-steel stock, and a thickness of 0·0025 in. nickel was deposited.

Results of examination of the characteristics of the 32 samples produced are reported graphically and in a series of electron micrographs, and hardness numbers are plotted against brightness.

The data presented show that there is no correlation between the brightness of nickel deposits and their grain size or hardness. Although there is a very broad general trend which indicates that the brightness increases with decreasing grain size and increasing hardness, the specific exceptions are so numerous that they may be considered as being more significant than the general trend.

Nickel Plating of Copper-base Materials

D. GRAY: 'The Preparation of Nickel Silver, Copper and Brass for Electroplating.' *Electroplating*, 1950, vol. 3, Dec., p. 605.

The article is condensed from a paper read at the 1950 meeting of the Electrochemical Society. It is based on the practice of Oneida, Ltd., in plating of hollow-ware (knives, forks, spoons, etc.) and flatware (cups, coffee pots, etc.) The abstract gives a general outline of the cycle of cleaning and plating operations used, but does not include any details of composition of cleaners, plating solutions, etc., or technique. A few general recommendations on choice and maintenance of cleaners are given.

Standard Specifications for Electrodeposited Coatings

'Plating to Specification.' *Plating Notes*, 1950, vol. 2, Oct., pp. 152-66.

Report of open discussion held by the Melbourne Branch of the American Electroplaters' Society, Aug. 17, 1950.

Contributions to the discussion were made by representatives of plating establishments, the Standards Association of Australia, and the Australian Defence Laboratories, all of whom gave practical details of specifications to which their respective plating shops work. A supplement to the discussion contains a list of British, Commonwealth, and American Standard Specifications and Codes of Recommended Practice Applicable to Electroplating. The list includes reference to standards issued by the following organisations: Standards Association of Australia; British Standards Institution; Ministry of Supply; Armament Research Department, Woolwich; New Zealand Standards Institution; American Standards Association; Society of Automotive Engineers; and American Society for Testing Materials, together with U.S. Army Airforce, Army-Navy-Aeronautical and Federal specifications.

Electrodeposition of Nickel-Rhenium Alloys

L. E. NETHERTON and M. L. HOLT: 'Electrodeposition of Nickel-Rhenium Alloys.' *Metal Finishing*, 1950, vol.48, Dec., p. 75.

The following brief abstract is made of a paper presented in October, 1950, to the American Electroplaters' Society:

'A bath containing 56 g./L. of nickel sulphate, 66 g./L. of citric acid and 10 g./L. of potassium perrhenate, at pH up to 8, produced a deposit containing 80 per cent. rhenium at 70°C., 5 amp./sq. dm. (45 amp./sq. ft.), and 90 per cent. cathode efficiency. Other baths for cobalt-rhenium and iron-rhenium were given.

The nickel-rhenium deposits were bright, and remained bright even after three months' exposure to the atmosphere. An outstanding characteristic was their excellent resistance to corrosion by concentrated sulphuric acid.'

NON-FERROUS ALLOYS

Monel in Pickling Equipment

HENRY WIGGIN AND CO., LTD.: 'The Use of Monel in the Pickling of Steel.' Publn. 419*: 1950. 32 pp.

The brochure forms a summary of experience on the use of Monel in plant employed in the pickling of steel, with recommendations on design, operating conditions, etc., which will give optimum results from the use of the alloy in this form of service.

The information is presented in three sections:—

1. *The Mechanism of Pickling*. A brief, simple, but fundamental discussion of the mechanism of pickling, which is now generally accepted as being electrolytic in nature. Requirements for a metallic material which, from the point of view of corrosion-resistance and mechanical strength will be suitable for pickling equipment, are reviewed and it is shown that Monel meets the specification.

2. *Pickling Plants*. The limitations of wood as a tank material are noted, and the importance of corrosion-resistance in the tie-rod material is emphasized. Anomalies observed in tie-rod corrosion are discussed, and the mechanism of the deterioration is considered, followed by recommendations for minimizing such failure, on an economically sound basis.

3. *Pickling Equipment*. A review is made of typical equipment used for pickling of billets and blooms; wire in coils; rods, bars and tubing; strip in coil; sheet and strip in straight lengths; hollow-ware and similar articles; miscellaneous articles. Much detailed design information is given, and the applications for which Monel is a suitable construction material are indicated.

*We shall be pleased to supply a free copy of this publication.

Diffusion of Copper in Nickel

See abstract on p. 30.

Effect of Nuclear Radiation on Nickel-containing Materials

See abstract on p. 28.

Chemical Analysis of Nickel Alloys

See abstract on p. 28.

NICKEL-IRON ALLOYS

Transformations in Iron-Rich Iron-Nickel Alloys

N. P. ALLEN and C. C. EARLEY: 'The Transformation $\alpha \rightarrow \gamma$ and $\gamma \rightarrow \alpha$ in Iron-Rich Binary Iron-Nickel Alloys.' *Jnl. Iron and Steel Inst.*, 1950, vol. 166, Dec., pp. 281-8.

The paper describes work carried out at the National Physical Laboratory, as part of an investigation of the influence of nickel on mode and rate of transformation in iron-nickel alloys.

The alloys were prepared from Swedish iron (melted in air in a magnesia crucible, which still further reduced the already low carbon, sulphur and silicon contents), and Mond nickel powder of high purity. The nickel contents of the alloys were 9·5, 13·3, 13·7, 14·6, 15·3, 16·2 and 18·0 at. per cent. Dilatometric, photomicrographic and X-ray methods of investigation were used. The experimental procedure and results are recorded in close detail, with many illustrations of the structural condition of alloys transformed at various temperatures and for various periods.

It was found that, on cooling iron-nickel alloys of the types studied, the γ-solid solution transforms into a supersaturated α-solid solution, α_2. During re-heating this solid solution decomposes; the isothermal transformation was followed closely by dilatometric and microscopical methods. The reaction proved to be complex, involving two types of phase change. During isothermal transformation of alloys within the duplex $\alpha+\gamma$ field, the supersaturated solid solution α_2 decomposes into two other solid solutions of different nickel contents, whereas, at similar temperatures, alloys initially in the γ-phase show no evidence of transforming isothermally $\gamma \rightarrow \alpha$. The kinetics of the slow isothermal transformation $\alpha \rightarrow \gamma$ are briefly discussed

Magnetic Alloys containing Nickel: Reference Data

R. M. BOZORTH: 'Factors Affecting Magnetic Quality.' *Bell System Technical Jnl.*, 1950, vol. 29, Apr., pp. 251-86.

The paper comprises the substance of Chapter II of a book entitled 'Ferromagnetism', to be published early in 1951, by D. van Nostrand Company, Inc. It forms a valuable source of reference, based on available literature and on the author's long experience in the field of magnetic materials.

The information contained is of too condensed a character to permit conventional abstracting, but the scope of the paper is indicated in the following skeleton of contents:—

The Importance of the Phase Diagram in relation to the preparation and properties of magnetic material, illustrated by reference to alloys characterized by various combinations of magnetic properties. The following table gives a summary of the influence of structure on magnetic properties, and factors which affect such properties.

Table I

Structure-Insensitive Properties	Structure-Sensitive Properties	Factors Affecting the Properties
I_s Saturation magnetization	μ Permeability	Composition (gross)
θ Curie point	H_c Coercive force	Impurities
λ_s Magnetostriction at saturation	W_h Hysteresis loss	Strain
K Crystal anisotropy constant		Temperature
		Crystal structure
		Crystal orientation

Production of Magnetic Materials (Melting and casting, fabrication, heat-treatment). Much detailed information on technique and equipment required.

Effect of Composition (Basis chemical composition, structure, hardening effects; the influence of impurities, e.g., carbon, oxygen, nitrogen).

Some Important Physical Properties of Magnetic Materials (Electrical resistivity, atomic diameter, changes in structure and controlled orientation; mechanical properties; size effects in powder materials). In this connexion, reference is made to properties which are affected by magnetization (length and volume, electrical resistivity, elastic constants, and rotation of plane of polarization of light). Attention is also directed to properties which change with temperature because magnetization itself changes; for example there is 'anomalous' temperature dependence of specific heat, thermal expansion, electrical resistivity, elastic constants, and thermoelectric force.

Properties of Nickel Ferrite

W. A. YAGER, J. K. GALT, F. R. MERRITT and E. A. WOOD: 'Ferromagnetic Resonance in Nickel Ferrite.' *Physical Rev.*, 1950, vol. 80, Nov. 15, pp. 744-8.

Full form of paper referred to in abstract, *ibid.*, 1950, vol. 79, p. 214; *Nickel Bulletin*, 1950, vol. 23, Nos. 8-9, p. 150.

The ferromagnetic resonance phenomenon in single crystals of $NiOFe_2O_3$ has been studied at room temperature at 24,000 Mc/sec. Small samples were used, in order to avoid electromagnetic cavity-type resonances. The g-factor observed is 2·19. The first-order magnetocrystalline anisotropy constant K_1 was found to be $-6{\cdot}27 \times 10_4$ ergs/cc. The absorption line was very narrow (half-widths less than 100 oersteds) and fits a resonance curve quite satisfactorily.

Nickel-containing Permanent-Magnet Alloys (Ticonal, Alconit)

C. VUILLEUMIER: 'Permanent Magnets.' *Von Roll Mitteilungen*, 1950, vol. 9, Dec., pp. 65-6.

The first section of this paper discusses fundamental principles of magnetism underlying the operation of permanent magnets, and some of the modifications in design involved in replacing the less powerful, older types of magnet alloys by the more recently developed grades.

Later sections deal with the metallurgy of permanent-magnet alloys, of martensitic and of precipitation-hardenable varieties, and the properties of Ticonal and Alconit alloys. Ticonal is an anisotropic material of aluminium-nickel-cobalt-copper-iron type, while the Alconit series (0, 10 and 16) are iron-base alloys containing nickel and aluminium, with or without cobalt. In the cobalt-containing grades of Alconit the numerical suffix indicates the cobalt content.

CAST IRON

Routine Foundry Production of Spheroidal-Graphite Cast Iron

M. M. HALLETT: 'Practical Experiences in Producing Nodular Cast Iron.' *Foundry Trade Jnl.*, 1951, vol. 90, Jan. 4, pp. 3-9; disc., pp. 9-12, 16.

In presenting his lecture, the author emphasized that it was his intention not so much to read a paper as to present a *progress report* on the position reached at the moment, and to deal with the subject purely from the foundry angle, considering theory only in so far as it facilitated understanding of the variations experienced in practice. The information given is based on experience in the foundries of Sheepbridge Engineering, Ltd., in production of magnesium-treated cast iron, under licence from The Mond Nickel Company, Ltd.

After a brief résumé of the practical limitations of the nodularizing or spheroidizing processes, the characteristics of the cerium method introduced by the

British Cast Iron Research Association were considered, and its somewhat restricted range of application was indicated. This was followed by a more detailed account of *foundry technique* now being used in the production of spheroidal-graphite cast iron by the magnesium (INCO/Mond) process. The advantages of a nickel-magnesium alloy as the magnesium-carrier were emphasized, and a step-by-step account was given of the *mode of addition* which had proved optimum. *Inoculation procedure* was also described in detail. Warning was given that, in order to secure consistently good results with the magnesium treatment, the pig irons used for the basis charge must be chosen with care: in this connexion, reference was made to the individual influence of the following elements: silicon, manganese, sulphur, phosphorus, nickel, chromium, tin, lead, arsenic, antimony, bismuth, selenium, tellurium, vanadium, titanium.

Founding properties of the new cast irons were considered in some detail (with emphasis on the importance of cleanliness, and advice on the introduction of slag traps and the use of teapot-spout ladles), and *shrinkage characteristics* were discussed (with examples of principles to be followed in arrangement of the running and feeding system and illustration of feeding heads found to be specially well suited for use in this connexion).

In reviewing *mechanical properties*, the author gave as average for the as-cast condition a tensile strength of 38-42 tons per sq. in., with an elongation equal to that of normal grey iron, and a toughness about two or three times that of ordinary grey iron, with Brinell hardness of the order of 280. In the annealed condition the tensile strength drops to about 30-33 tons per sq. in., but the elongation rises to a value of 15-20 per cent. The toughness, in this condition, is far greater than that of grey cast iron, and machinability is excellent at the lower hardness value of about 180. It is emphasized that these are *average figures*; values as high as 50 tons per sq. in. have been recorded, and elongation values, in the heat-treated condition, have at times reached 25 per cent.

With regard to *applications*, the author considers that the new cast irons are to be regarded, in the as-cast condition, as a development of a super-high-duty grey cast iron, whereas the annealed material is more competitive with malleable iron and with carbon-steel castings.

Testing of Grey Cast Irons

C. K. DONOHO: 'Mechanical Testing and Properties of Grey Cast Iron.' *Foundry Trade Jnl.*, 1950, vol. 89, Dec. 21, pp. 523-7.

Tests generally used in assessing the properties of grey cast iron are reviewed, on the basis of their ability to provide data practically useful in design and service. Schedules which have been standardized for tensile, transverse, hardness and impact testing are briefly considered, and charts which may be used for correlation of hardness with tensile and transverse strength are shown.

It is pointed out that the testing of nodular-graphite cast iron presents problems which are to some extent different from those involved in the testing of ordinary grey irons. Since the material may have appreciable ductility, and may vary considerably, according to physical conditions, with regard to this property, a simple tensile test for strength is inadequate as a specification test. More satisfactory information may be obtained from the transverse test, by measuring deflection values and plotting stress-strain curves. Typical transverse stress-strain curves for a flake-graphite and a nodular-graphite cast iron are shown.

Tensile testing of nodular-graphite iron should be carried out by the methods used for malleable iron or cast steel, including determinations of yield point and percentage elongation as well as of tensile strength. The author considers the testpiece recommended in the Steel Castings Handbook as the most suitable. The keel block mould in this case is so designed that the legs, or coupons, are perfectly fed, and tensile specimens machined from it are free from shrinkage. This type of test bar is believed to show the true properties of a cast material in its best physical condition. Data obtained by it on a nodular iron are compared, in the paper, with others obtained on a specimen from a bar to A.S.T.M. specification A-48, bar B, indicating the error which may be introduced by not using a shrinkage-free test bar. The tensile specimen generally used for malleable iron has also been tried for testing nodular cast irons, but the indications are that it needs re-designing if it is to give consistent and representative results on the new irons.

A curve shows that tensile/hardness relationships in nodular iron more nearly approach those ruling for steel than those found in grey irons. The compressive strength/Brinell ratio is, however, of the same order, whether the irons are of nodular- or flake-graphite type. This finding is supported by tests on pipe cast in (1) grey iron, and (2) nodular iron. Whereas the bursting strength of the nodular- was twice or three times that of the flake-graphite iron, collapse tests (really a compression test applied by hydraulic pressure) showed little difference between the two materials, being, in both cases, nearly proportional to the hardness.

Growth Tests on Spheroidal-Graphite Cast Iron

T. E. EAGAN: 'Comparative Growth of Gray Iron vs. Nodular Iron when Cyclically Heated to 1650°F.' *Foundry*, 1950, vol. 78, Dec., pp. 96-9, 203-4.

Growth occurring in unalloyed grey cast iron when subjected to elevated temperatures is an effect which in many cases precludes the use of this material for applications in which its other properties would be suitable. Preliminary tests by Gagnebin and Pilling indicated that magnesium-treated spheroidal-graphite cast iron shows excellent resistance to growth, a feature which is attributed to the fact that graphite flakes offer easy paths to penetration by oxidizing gases, whereas the nodular or spheroidal form of graphite is more obstructive.

The growth test used by Gagnebin and Pilling consisted in heating to 1600°F. (870°C.), holding for 1½ hours at that temperature, and air cooling, this cycle being repeated 100 times. The results showed clear superiority for the spheroidal-graphite iron, both

with regard to actual growth, and resistance to oxide penetration.

The present authors carried out somewhat similar tests, but protected the samples from atmospheric contamination, in order to determine whether growth was entirely due to oxygen penetration, to graphitization, or to a combination of the two.

Three specimens of spheroidal-graphite cast iron were exposed, one in the as-cast and one in the annealed condition, supplemented by a specimen cut from an experimental gas-engine piston which had been annealed under commercial conditions. These samples, after length measurements, were packed in a container, in fresh dry iron chips, and were sealed in with fireclay. They were heated to 1650°F. (898°C.) in an electric furnace, held for one hour at that temperature, furnace cooled, and again measured. This procedure was followed with holding times of 2, 4, 8 and 22 hours, making a total holding time of 36 hours.

The effect of such heating on mechanical properties of the irons was also investigated, and microstructural examination was made.

Tables I, II and III give the compositions of the irons used and a summary of the results.

These data appear to justify the following conclusions:—

(1) Spheroidal-graphite cast iron, when cyclically heated into the austenitic range, and cooled, showed much less growth than grey iron. After an initial small amount of growth the iron becomes relatively stable.

(2) Growth of grey iron is considerable under the same conditions of treatment. It is dependent on the carbon equivalent of the iron and whether it contains any carbide-stabilizing alloys, such as chromium.

Table I
Chemical Analysis of Materials Used

	T.C.	Si	Mn	P	S	Ni	Cr	Cu	Mo	Mg
1. Class 25 grey iron	3·27	2·27	0·68	0·20	0·15	—	—	—	—	—
2. Class 35 + alloy grey iron	3·19	2·10	0·93	0·16	0·092	—	—	1·12	0·37	—
3. Class 40 grey iron	3·15	1·28	0·90	0·093	0·10	—	—	—	—	—
4. Class 40 + alloy grey iron	3·06	1·55	1·01	0·078	0·069	0·98	0·341	—	0·24	—
5. Nodular iron, as cast (2)	3·43	2·19	0·47	0·13	0·009	1·95	—	—	—	0·077
6. Nodular iron, heat-treated(1)	3·50	2·56	0·54	0·12	0·010	1·50	—	—	—	0·055
7. Nodular iron, heat-treated(2)	3·43	2·19	0·47	0·13	0·009	1·95	—	—	—	0·077

(1) Cut from an experimental piston after heat-treating. (2) Cut from a 4·5-in. wide keel-block casting.

Table II
Growth at 1650°F. (898°C.) for Various Holding Periods

Specimen No.	1 hour		2 hours		4 hours		8 hours		16 hours		36 hours	
	Total growth in 8 in.	Growth in 1 in.	Total growth in 8 in.	Growth in 1 in.	Total growth in 8 in.	Growth in 1 in.	Total growth in 8 in.	Growth in 1 in.	Total growth in 8 in.	Growth in 1 in.	Total growth in 8 in.	Growth in 1 in.
1	0·053	0·0066	0·097	0·0121	0·137	0·0171	0·198	0·025	0·364	0·083	0·581	0·073
2	0·043	0·0054	0·055	0·0069	0·075	0·0094	0·107	0·0134	0·199	0·025	0·420	0·052
3	0·018	0·0023	0·024	0·003	0·035	0·0044	0·050	0·0063	0·092	0·0012	0·174	0·022
4	0·009	0·0011	0·013	0·0016	0·017	0·0021	0·025	0·0031	0·036	0·0045	0·056	0·007
5	0·014	0·0018	0·020	0·0025	0·024	0·003	0·027	0·0034	0·039	0·0049	0·039	0·0049
6	0·014	0·0018	0·024	0·0031	0·030	0·0038	0·031	0·0039	0·032	0·004	0·033	0·0041
7	0·014	0·0018	0·015	0·0019	0·015	0·0019	0·016	0·002	0·016	0·002	0·019	0·0024

Table III
Properties Before and After Heating

No.	Material†	Condition	Original Properties						After 36 hours at 1650°F. (898°C.)				
			U.T.S.		Yield		Elong-ation %	B.H. No.	U.T.S.		Yield	Elong-ation %	B.H. No.
			p.s.i.	t.s.i.	p.s.i.	t.s.i.			p.s.i.	t.s.i.			
1	Cast iron 25	As-cast	30,600	13·65	—	—	—	193	5,800	2·6	re-test	—	—**
2	Cast iron 35 + Cu and Mo	As-cast	45,500	20·3	—	—	—	269	13,250	5·95	—	—	111
3	Cast iron 40	As-cast	52,600	23·5	—	—	—	255	27,100	12·10	—	—	143
4	Cast iron 40 + Ni, Cu and Mo	As-cast	53,100	23·65	—	—	—	255	45,100	20·15	—	—	187
5	Nodular iron	As-cast	79,500	35·5	—	—	—	285	81,100	36·15	62,800	2·5	197
6	Nodular iron*	Annealed	65,600	29·3	53,000	23·6	7·0	166	69,800	31·15	69,600	0·0	187
7	Nodular iron	Annealed	71,000	31·7	57,300	25·6	7·5	179	78,100	34·85	64,600	2·5	187

* Taken from the skirt of a piston. ** Crumbled under Brinell test.

† The numerical values shown after the irons are A.S.T.M. grades.

Graphitizing elements apparently do not prohibit growth if they are present in quantities insufficient to maintain an austenitic matrix.

(3) Growth on heating is due to a combination of oxide penetration and graphitization.

(4) Oxide penetration is helped when the graphite is in the flake form and is resisted by the nodular or spheroidal form.

(5) The cyclic treatment described is very detrimental to the mechanical properties of grey cast iron unless a carbide stabilizer is present in sufficient amount. The same heat-treatment, however, increases the tensile strength of the magnesium-treated iron, while lowering the ductility, as indicated by elongation values.

Machinability of Spheroidal-Graphite Cast Iron: Influence of Annealing

J. F. KAHLES and R. GOLDHOFF: 'Anneal Ductile Iron for Better Machinability.' *Iron Age*, 1950, vol. 166, Dec. 14, pp. 105-8.

A report is made of investigations, at the University of Cincinnati, designed to correlate the influence of annealing on the mechanical properties and machinability of two basic types of ductile cast iron:—

(1) carbidic irons, the ductile irons of usual composition, which, when cast in thin sections, show appreciable quantities of free iron carbide;

(2) regular ductile irons having spheroidal graphite in a matrix of pearlite and ferrite. (In view of the preponderance of pearlite in relation to ferrite, in the as-cast structure of this type of iron, it is frequently referred to as pearlitic, in contrast with the carbidic irons.)

Full analyses of the samples of the two types are given.

Curves and tables give data on decomposition of pearlite and/or iron carbide under various conditions of heating; pearlite decomposition is correlated with the type of iron, and mechanical properties and tool life in turning tests are studied as functions of the amount of pearlite present. The machining tests were made almost exclusively on material of the following composition: total carbon 3·58, silicon 2·33, sulphur 0·010, manganese 0·40, phosphorus 0·052, nickel 1·55, magnesium 0·076, per cent.

Tests on this iron, after annealing to produce various amounts of pearlite, gave the average values shown in the table below.

Table I

Amount of Pearlite %	Tensile Strength		Yield Point		Elongation %	Reduction of Area %	Brinell Hardness
	p.s.i.	t.s.i.	p.s.i.	t.s.i.			
65	103,000	46·00	—	—	6·5	3·5	230
50	80,000	35·75	60,000	26·80	16·0	12·0	200
20	75,000	33·50	55,000	24·55	19·0	15·5	180
3	77,000	34·40	62,000	27·70	20·0	22·0	180

In this iron considerable improvement in machinability was obtained by annealing so as to transform the structure from 65 per cent. pearlite to 20 per cent. pearlite, but only slight further change was observed after continuing the annealing treatment to a stage giving 3 per cent. pearlite. The authors therefore conclude that for a ductile iron of this composition the most economical structure, from the standpoint of machinability, is the 20 per cent. pearlite condition, obtained by annealing at 1275°F. (690°C.) for only 1½ hours. The values shown in the above table also demonstrate that relatively high ductility is obtained before pearlite is completely removed.

The authors point out that their results, together with other experience, indicate that in ductile cast irons it is possible to predict machinability from structural condition. Such correlation has also been found by FIELD AND STANSBURY in other types of cast iron (U.S. Air Force Machinability Report, Curtiss-Wright Corporation, 1950).

Chemical Analysis of Nickel Alloys

See abstract on p. 28.

Acicular-Cast-Iron Crankshafts

A. FINLAYSON: 'Diesel Engine Crankshafts Cast in Gray Iron.' Reprint from *Foundry*, Aug. and Sept., 1950. Issued by International Nickel Co., Inc., 1951.

For scope of this article see *Nickel Bulletin*, 1950, vol. 23, No. 11, pp. 210-11.

Nickel-containing Cast Irons and Steels in Machine Tools

W. MOUNCE and J. E. FIFIELD: 'The Rôle of Nickel in the Machine Tool Industry.' Published by International Nickel Co., Inc., 1950; 30 pp.

Following a brief introduction dealing with recent advances in design which have been introduced into the machine-tool industry, a detailed review is made of factors influencing the selection of steels and of cast irons for various components, and of the composition and properties of nickel-containing cast irons and steels suitable for various applications.

In the section relating to cast irons used in machine tools, tabular data are presented on the engineering properties of nickel-alloy cast irons conforming to the A.S.T.M. 30, 40, 50, 60, 70 and 80 classes, and a comparison is made between the mechanical characteristics of grey iron class 40, malleable cast iron, and ductile (magnesium-treated) cast iron, the latter being shown for both the as-cast and the annealed conditions.

Comparative machinability and gall-test data are also tabulated for grey, acicular (flake-graphite) and ductile (spheroidal-graphite) cast irons. The beneficial effects of nickel additions to the various grades of cast iron used in this industry are discussed at some length. Information is also given on heat-treatments (annealing, stress-relieving, hardening) suitable for cast irons.

In the second section of the publication the subject is considered in relation to the individual components of the machine tools for which nickel-containing materials may be used: columns, arms, rams, etc.; spindles, shafts, levers and screws; clutch parts; hydraulic applications; bearings and bushings; precision components; chucks; tool holders and cutter bodies. Although the major emphasis is on constructional steels and cast irons, attention is also directed to the applications of non-ferrous materials in this field, e.g., nickel-containing bronzes for worms and worm gears, and for bushings. Compositions and properties of bronzes so used are tabulated. For machine-tool parts in which close dimensional tolerances must be maintained and somewhat unusual physical properties are imperative, the alloy cast iron Minovar (characterized by low thermal expansion) has met a growing need.

The publication is profusely illustrated with examples of machine tools and components embodying parts made from the materials described.

CONSTRUCTIONAL STEELS

Oxygen Enrichment in Production of Nickel-Alloy Steels

See abstract on p. 40.

Heat-Treatment and Forming of Nickel Steel for Boilers and Pressure Vessels

'Suggested Heat Treatment and Forming Data for Boiler and Pressure Vessel Steels.' *Welding Jnl.*, 1950, vol. 29, Dec., Suppl., p. 622-3.

This tabulated summary, prepared by the Pressure Vessel Research Committee of the American Welding Society, provides, in convenient reference form, the following particulars relative to the steels standardized for the above use: A.S.T.M. specification numbers, chemical requirements, tensile-strength requirements, thickness range, annealing and normalizing treatments, and hot-forming temperature range.

The steels for which these data are shown include the nickel steels covered by A.S.T.M. A.203, containing, respectively, 2·00-2·75 and 3·25-3·75 per cent. nickel, at various carbon levels.

Evaluation Tests for High-Strength Alloy Steels

G. SACHS, G. S. SANGDAHL and W. F. BROWN: 'New Notes on High-Strength Heat-Treated Steels.' *Iron Age*, 1950, vol. 166, Nov. 23, pp. 59-63; Nov. 30, pp. 76-80.

The authors discuss the methods available for evaluation of the mechanical properties of heat-treated steels, illustrating their arguments and conclusions by data on three types of steel which they have used throughout a series of systematic investigations on this subject: S.A.E. 2340 (nickel), 5140 (chromium), 1340 (carbon-manganese) and 1050 (high-carbon). Laboratory-produced and commercial steels of each type were included.

The specimens of any one type of steel were closely

similar in composition with the exception of the aluminium content; the commercial steels contained approximately 0·03 per cent. aluminium, while the experimental heats contained less than 0·005 per cent.

The limitations of the conventional tests, for full assessment of the qualities of high-strength heat-treated steels are reviewed, and a report is made of tests (V-notch impact and concentric notch-bar tensile) on the steels referred to above. The steels were heat-treated to different strength values, by various methods of quenching and tempering. Full particulars are given of the treatment applied to the individual steels, also a description (with illustration) of the concentric notch-bar-tensile specimen and mode of test.

The results indicate that properties revealed by such tests are not decisively influenced by grain size, but that hardenability is a factor of major importance. The higher the hardenability the more easily and consistently can the fully martensitic structure and optimum strength properties be developed. Reference is directed to published literature indicating the adverse effect of slack quenching, with resulting deviations from the martensitic structure. Sub-zero treatment had only a slight effect on the properties investigated.

Variation in properties between slack- and fully-quenched specimens as a function of size of specimen was considerable, but the percentage decrease in properties with increase in specimen size was much smaller in the nickel steel than in either the manganese or the chromium steel. The nickel steel retained its high notch strength up to the maximum size tested (1·25 in. diameter, machined from 1½-in. diameter hot-rolled stock), as compared with the chromium and manganese steels, which both showed considerably reduced notch strength in as-quenched diameters of over 0·30 in.

Strength of Wrought Steels at Elevated Temperatures: Summary Data

See abstract on p. 43.

Chemical Analysis of Nickel Alloys

See abstract on p. 28.

Effect of Nuclear Radiation on Nickel-containing Materials

See abstract on p. 28.

Nickel-containing Steels in Machine Tools

See abstract on p. 38.

Nickel Steels in Wood-Cutting Tools

H. A. PAVITT: 'Steel Used in the Cutting of Wood.' *Amer. Soc. Mechanical Engineers*, Preprint 50-F-30, Sept., 1950; 4 pp.

The author reviews the types of tool used for cutting wood at various stages: crosscut, pulpwood, circular, and bandsaws; planer, veneer, chipper, and hog knives. The functions of each of these tools are noted, and materials which have proved suitable for them are detailed.

Cross-cut saws used for felling trees are of a high-carbon unalloyed steel, which gives the necessary properties and is economically acceptable. Pulpwood saws are of the same composition, but are subjected to a different heat treatment, to modify the properties. Bandsaws or circular saws, used for cutting logs into lumber at the saw mill, are operated by steam, electric-motor or diesel-power plant, delivering up to 100 h.p. With this power saws up to 60 in. diameter are employed and are operated at 600-900 r.p.m. In such conditions a combination of strength, abrasion-resistance and toughness is required, coupled with filability, and the capacity for retention of properties over a considerable temperature range. For circular saws a steel containing carbon 1·75, nickel 2·5, per cent. has been found to give the best service, and to have the advantage of ease of manufacture. The steel is characterized by strength, accompanied by toughness, at hardness levels of Rockwell 45-50 C, a combination which it has been found difficult to obtain in other alloy steels.

Veneer is obtained by turning logs in a lathe and cutting a continuous sheet of wood of the desired thickness. Veneer knives require the properties of hardness, toughness and abrasion resistance, in order to withstand the impact involved in cutting knots, mineral deposits often present in the wood, the abrasive properties of the wood fibres, and variations in temperature developed in service. The author reports that a steel containing carbon 0·80, nickel 2·75, vanadium 0·25, per cent. has proved to fulfil all these requirements. In some cases, additions of chromium and molybdenum are found desirable, in order to add to the abrasion-resisting qualities of the steel, and to enhance stability at raised temperature.

Chipper knives are made from a steel of the carbon 0·50, chromium 8·50, per cent. type, with 1 per cent. each tungsten and molybdenum; it gives good resistance at raised temperature, and shows good edge-holding properties.

For planer knives, jointers and shapers, which operate at fairly high speeds and feeds and are subjected to hardness and impact of knots and other abrasives, a high-carbon chromium-tungsten-vanadium-molybdenum steel has proved serviceable.

A 2·75 per cent. nickel steel of the 0·75 per cent. carbon type is employed for cut-off saws, planer saws, glue-joint saws, etc., which are required to have a hardness and toughness ensuring resistance to the impact and vibration involved in cutting. Tough saws have been produced from this steel in the range Rockwell 45-52 C.

Saws required in applications which call for special abrasion resistance are made from a steel containing carbon 0·80, tungsten 5·75, vanadium 1·80, molybdenum 5, per cent. This type of steel requires that the plant shall be equipped with shops in which the saws can be ground.

In applications meriting the expenditure carbides are to be recommended. The carbide saw is made from a plate which has a composition similar to that used in the regular saws (carbon 0·70, nickel 2·50, per

cent.), heat-treated to Rockwell C 45, to ensure maximum strength and minimum notch sensitivity. The carbide is brazed to the plate to form the tips of the teeth, at a temperature which does not adversely affect the strength and toughness of the plate. The major usefulness of such saws is in equipment which is rigid and relatively free of vibration, and has adequate speeds and feeds.

HEAT- AND CORROSION-RESISTING ALLOYS

Oxygen Enrichment in Production of Nickel-Alloy Steels

M. HAUCK and H. WERWACH: 'The Use of Oxygen in Arc Furnaces.' *Stahl und Eisen*, 1951, vol. 71, Jan. 4, pp. 15-18.

Report of experience in Stahlwerke Bochum, A.G., recording tests made to determine the potential usefulness and economic value of using oxygen-enriched blast in the production of plain and low-alloy steels.

Normal control tests, applied to the steels produced in these conditions, showed properties equal to those of steels made without oxygen-enrichment, working costs were reduced, and production capacity of the furnace was markedly increased. Savings effected by reduction in chromium loss amounted to 3-4 kg. chromium per ton of steel. Initial difficulties with regard to maintenance of normal life of hearth have been overcome.

See also—

F. ILLIAN: 'The Use of Pure Oxygen in Refining of Stainless Chromium-Nickel Steels.' *ibid.*, p. 18-19.

This note records work in the Deutsche Edelstahlwerke A.G., Krefeld, in the production of 18-8 type steel, with or without small tungsten additions. In this case also the steels produced are found to be of good quality and to show good machinability. Flask oxygen is used, introduced by lance. The charge consists of 100 per cent. chromium-nickel steel scrap, and it is found that, using scrap of up to 0·10 per cent. carbon content, the carbon of the final product can be reduced to 0·06-0·07 per cent. A table shows oxygen used and reduction effected in carbon content for typical heats containing 0·21-0·15 per cent. carbon.

Relations established between the chromium content of the melt, the final carbon value and the reaction temperature are discussed, and a curve shows chromium loss as a function of carbon content of the finished steel. This indicates that reduction of the carbon to very low levels is associated with heavier loss of chromium. In the high-carbon valve steel, the presence of silicon partially inhibited loss of chromium. The following values are quoted as typical of the melting loss of the respective elements when the oxygen treatment was used:—

Silicon ..	1·78 to	0·27%=85% loss
Carbon ..	0·49 to	0·18%=62% loss
Manganese	1·00 to	0·41%=59% loss
Chromium	16·00 to	15·20%= 5% loss
Tungsten	1·03 to	0·98%=4·5% loss (value given with reservation)
Nickel	showed no change	

No accurate figures are yet available for losses in tantalum and niobium, but, on the basis of the affinity of these elements for oxygen, it would be anticipated that tantalum would be the more stable and that niobium would be totally lost. Copper showed little or no loss, the value of 5 per cent. being only of the order of that encountered in normal practice.

Use of oxygen enrichment, under suitably controlled conditions, has been found to effect appreciable saving in electrodes and a reduction in the amount of current required. Sintered magnesite has proved to be the most satisfactory material for the hearth.

A brief note is added on successful preliminary trials on oxygen lancing in the melting of plain and alloy tool steels.

Sigma Formation in Stainless: Causes and Effects

G. V. SMITH: 'Sigma Phase in Stainless; What, When and Why.' *Iron Age*, 1950, vol. 166, Nov. 30, pp. 63-8; Dec. 7, pp. 127-32.

This review is an attempt to fill in gaps left by papers presented at the A.S.T.M. Symposium on Sigma (see *Nickel Bulletin*, 1950, vol. 23, No. 8-9, pp. 158-61), and to condense existing knowledge, with a view to clarifying the lines on which further research is urgently needed.

The subject is discussed from the aspects shown below: some of the major contents of the paper are briefly indicated.

Although laboratory studies have shown that *sigma occurs in many ternary or multi-component alloys*, the constitutional diagrams involved are not, with the exception of the iron-nickel-chromium system, well known. It has been shown that in this range of alloys sigma may form directly from either ferrite (alpha) or austenite (gamma).

Influence of alloy elements on sigma formation is determined very largely by whether such addition has changed the material from a completely austenitic condition to a duplex austenitic-ferritic structure. The different affinities of the addition elements for carbon and nitrogen may also indirectly affect the composition of the alloy. To date it has been found that nickel, in small amounts, widens the range of composition in which sigma occurs, but that larger proportions yield alloys which are immune from sigma formation, e.g., the 35-15 nickel-chromium-iron alloys. Increase in carbon diminishes the tendency to sigma formation, and theoretical reasoning would appear to indicate that nitrogen should have a similar influence: this has, however, been contradicted. The effect of manganese is similar to that of nickel, but manganese is somewhat more soluble in sigma than is nickel. The

ferrite-forming elements appear to enhance precipitation of sigma, both with regard to widening of the range of composition in which it may occur and in accelerating rate of precipitation. In this category are silicon, molybdenum, niobium, titanium, zirconium and aluminium. It is pointed out that an unknown constituent reported by ANDREWS as occurring in molybdenum - containing nickel - chromium steels should not be confused with sigma (see *Nature*, 1949, vol. 164, p. 1015).

Mode of formation of sigma is still controversial, but the author believes that, for all but a few investigators, doubt that sigma may form directly from austenite, as well as from ferrite, has been dispelled by reports of a number of studies in which no phases other than sigma, austenite and carbide were observed during formation of sigma in steels which were initially wholly austenitic. Rate of formation is, however, slower from austenite than from ferrite, and there are certain differences in the intermediate structures under the two conditions. Rate of formation of sigma depends, within wide limits, on composition, prior history, and temperature, but the exact effects of these variables require further study.

Review of the *etchants which have been used for identification of sigma* (with some photomicrographs illustrating the delineation obtained) leads to the conclusion that no universally satisfactory etching procedure has yet been developed for this purpose, and that microscopical examination should be supplemented by magnetic-permeability, hardness, and X-ray diffraction tests.

Consideration of the *influence of sigma on properties* is grouped into two sections, covering respectively, mechanical properties and corrosion-resistance.

The deleterious effect of sigma on room-temperature ductility is illustrated by typical data on austenitic steels of the straight nickel-chromium type and steels containing stabilizing and other addition elements, e.g., molybdenum; the lowering of elevated-temperature strength and ductility in certain sigma-containing alloys is demonstrated by reference to published reports. It is pointed out, however, that in some of the complex steels examined by certain investigators it is possible that carbide precipitation, rather than, or in addition to, sigma formation, may have been responsible for loss of toughness. Reference is also made to the fact that in at least one type of steel (chromium 25, nickel 5, molybdenum 3, per cent.) sigma formation is intentionally induced, in order to obtain a degree of hardness and wear-resistance found desirable in automobile-valve applications.

With regard to the influence of sigma on corrosion-resistance, published evidence, although indicating deterioration in corrosion-resistance of sigma-containing materials, is not regarded as conclusive. Since carbide precipitation occurs within the same temperature range as sigma formation, it is somewhat difficult to determine the exact rôle of the latter, but the conclusion that sigma is detrimental in austenitic alloys may be based on comparison of fully austenitic material with material containing some delta ferrite which transformed to sigma. Additional evidence that sigma may in some instances adversely affect the corrosion-resistance of austenitic steels has been adduced from the fact that the newly developed extra-low-carbon stainless steels have not, in all cases, proved immune from susceptibility to intergranular sensitization. This susceptibility has been attributed to sigma formation, but only in one case has direct experimental evidence been advanced. (This is briefly summarized by the present author.) It is also pointed out that although intergranular sensitization of molybdenum-containing stainless steels may result from precipitation of sigma, it is, unlike the sensitivity resulting from carbide precipitation, observed only in the nitric-acid test, not in the other test media which have been used for detection of intergranular breakdown. In addition, prolonged heating in the sensitization range restores resistance to nitric acid, indicating that sigma is apparently detrimental in this respect only under strictly specific conditions, requiring a very fine intergranular dispersion when subjected to nitric acid attack.

With regard to *elimination of sigma-embrittlement*, the reminder is added that sigma may be re-dissolved in austenite, or converted into delta ferrite, by heating above the maximum temperature of stability of sigma. Such treatment substantially restores the original properties. A considerable degree of ductility can be restored to steels embrittled by sigma formation, by heating for as short a time as 10 minutes at 1900°F. (1035°C.), although complete conversion of sigma to austenite may require heating at a temperature as high as 2250°F. (1230°C.). If such temperatures of treatment are required, grain growth has to be anticipated, with associated alteration in properties.

Influence of Stress-Ageing Treatment on High-Nickel Ferrous Materials

R. F. GILL and R. H. HARRINGTON: 'Stress-Ageing Treatment and its Effects on the Physical Properties of Copper-, Iron-, and Aluminium-base Alloys.' *Jnl. Inst. Metals*, 1950, vol. 78, Nov., pp. 203-28; Advance Copy 1277; *Monthly Jnl.*, Nov., 1950.

'Stress-ageing' is defined as a 'new treatment consisting of heating of alloys composed wholly or in major part of a solid-solution phase (or phases) for correct times, at suitable temperature, while the material is subjected to stress from an external load.' By means of such treatment it has been found possible to produce remarkable improvements in mechanical properties, and also, in some cases, in electrical conductivity.

The most effective stresses have been found to be those ranging from the proportional limit to the 0·2 per cent. yield strength of the alloy in its previously prepared condition (i.e., as annealed, as cold-worked, or as heat-treated). Since, in almost all instances, the proportional limit is below the elastic limit, such a stress will usually not result in any material creep for periods of 4-20 hours. In many cases, stresses as high as the 0·2 per cent. offset yield strength are so close to the elastic limit that the creep resulting from such a stress during a period of 4-20 hours is either immeasurably small or negligible, as regards any effect

on dimensions. The effective temperatures for stress-ageing are those within the range from room temperature to the recrystallization temperature of the alloy concerned. Above the recrystallization temperature, the annealing (or re-solution) reaction exceeds the stress-ageing reaction, and creep under such high stresses is very rapid and completely damaging.

This paper reports tests of the effect of stress-ageing treatment on three groups of material:

(1) *Copper-base alloys* (70/30 brass, leaded high-copper brass, phosphor bronzes, copper-cadmium alloy and aluminium bronze).

(2) *Iron-base alloys* (18-8 stainless steel, 64/36 per cent. iron-nickel alloy, 79/19/2 and 71/18/11 iron-nickel-chromium alloys, and Ni-Span C, containing nickel 42, chromium 5·5, titanium 2·5, balance mainly iron).

(3) *Aluminium-base alloys* (eleven alloys containing, in varying proportion and combination, the following elements: silicon, manganese, magnesium, zinc, chromium, lead, and bismuth).

Treatments and test methods are very fully described, and individual results are given relating to the influence of stress-ageing treatments on the mechanical properties of the materials and their structure. In the case of the copper-base alloys, changes in electrical conductivity are also described.

The current stage of development of the method, the conclusions to be drawn from the experimental results reported, other data at present available, and the potential usefulness of the process as a means of improving high-temperature materials are concisely summarized in concluding sections of the paper, under the following headings:—

1. *Factual Bases.* The effective use of stress-ageing to improve mechanical properties runs counter to earlier accepted theories on methods potentially useful for strengthening alloys, but its validity is proved beyond suspicion.

The beneficial effect of stress-ageing increases with increase in applied stress, increase in ageing temperature (until such temperature is reached that the tendency to anneal exceeds the stress-ageing reaction), and increase in time at temperature of stress-ageing. In general, a period of 20 hours accomplishes practically complete stress-ageing, although alloys having exceptionally slow diffusion rates would respond to longer treatment.

The beneficial effects of stress ageing increase with increase in solute-metal content, but relatively small amounts of alloy content may be very effective, e.g., in copper containing only one per cent. of cadmium.

Maximum stress ageing for any specific alloy may effect the following increases in engineering properties: from 20 to 150 per cent. for the proportional (or elastic) limit; up to 100 per cent., for the 0·2 per cent. offset yield strength; up to 50 per cent. for the tensile strength; up to 75 per cent. for elongation, and up to 50 per cent. for electrical (and heat) conductivity. Possible effects of stress ageing are diagrammatically illustrated.

2. *Theoretical Considerations.* Theoretical considerations relating to the physical properties of metals and alloys and their crystal structure and recrystallization temperatures indicate that (*a*) alloys which recrystallize at or below room temperature cannot be stress-aged to any practical degree; (*b*) alloys with higher melting points will require greater applied stresses for maximum ageing results; (*c*) the stress-aged condition for any specific alloy will have about the same elevated-temperature stability as does its cold-worked condition; (*d*) a considerable change in crystal structure seems necessarily to be involved in stress-ageing, but it probably takes place within submicroscopic strain-gradient volumes.

3. *Practical Methods of Stress-Ageing in Tension.* The suggestion is made that stress-ageing may be effected by (*a*) compression, extension or deflection of formed springs or strip with simultaneous heating, e.g., by high frequency; (*b*) heating, by resistance methods, of lengths of strip or wire under tensile stress; (*c*) 'strand' stress ageing, on the same principle as strand-annealing but with suitable modification of temperature, such treatment being applicable to strip and wire, and with modification, to plate and rod stock; (*d*) high-frequency heating of structural parts maintained under stress.

4. *Practical Significance of Stress-Ageing.* It is suggested that—

(*a*) if parts are stress-aged, present operational stresses may be borne by half (or less) of the cross-section at present used, and present operating parts may support twice the present operational stresses (or more). Such 2:1 ratio applies for the many alloys which have the capacity to stress-age to at least double their original proportional and elastic limits. Lower savings would occur with alloys which have smaller inherent stress-ageability;

(*b*) the engineering evaluation of commercial alloys would be altered by the use of stress-ageing treatment, e.g., copper-cadmium and 70-30 brass alloys would develop spring properties approximately equivalent to those of heat-treated beryllium copper.

Improvements in elastic properties (combined with maintenance or improvement of elongation, already proved), give promise that stress-ageing treatment should also effect improvement in endurance properties and creep resistance. It is also suggested that the stress-ageing reaction may dominate the second stage of creep.

B.S. Specifications for Creep- and Stress-Rupture-Testing

'Long-Period, High-Sensitivity Tensile Creep Testing.' B.S. 1686:1950.

This Standard specifies the essential requirements for testing machines and methods of test to be employed to measure tensile creep (total plastic) strains down to 0·001 (0·1 per cent.) and in periods up to 10,000 hours. It is applicable to standard tests on specimens from bars, plates, sections, and sheets, and specimens from components of sufficient size to enable the required specimens to be prepared.

'Medium-Sensitivity Tensile-Creep Testing.' B.S. 1687: 1950.

This Schedule is closely parallel to 1686 (above), but

relates to the measurement of tensile strains of 0·01 (1·0 per cent.) or greater, in periods up to 10,000 hours. Its range of applicability is identical with that of 1686.

"Determination of Times to Rupture under Stress.' B.S. 1688:1950.

This Standard covers requirements for testing machines and methods to be employed to measure times of rupture, with or without measurement of creep strain, under constant tensile loads and at constant temperatures. Its range of application is as 1686 and 1687.

All three schedules include an Appendix giving a table of fixed temperature points required for calibration of base-metal and precious-metal thermocouples.

Effect of Nuclear Radiation on Nickel-containing Materials

See abstract on p. 28.

Strength of Wrought Steels at Elevated Temperatures: Summary Data

AMER. SOC. TESTING MATERIALS: '100,000-Hour Rupture Data for Wrought Steels.' *A.S.T.M. Bull.*, 1950, No. 170, Dec., p. 9.

In 1950 the American Society for Testing Materials issued, under the authorship of HEGER and MILLER, a lengthy report on 'Strength of Wrought Steels'. For scope see *Nickel Bulletin*, 1950, vol. 23, Nos. 8-9, pp. 163-4.

Subsequent to the issue of that report the authors have prepared a tabulation of data for rupture strengths of wrought steels at a rupture time of 100,000 hours. These are now published as a supplement. The range covered is 900°-1600°F. (482°-871°C.) and the materials included, on which property data are given (in most cases for parts only of this range) are of the following types:—

Carbon steel.

Molybdenum steel (0·5 per cent.).

Chromium-molybdenum steels (0·5/0·5, 1/0·5, 1·25/0·5, 2/0·5, 2·25/1, 5/0·5, 7/0·5, 9/1, per cent.)

Chromium-molybdenum-silicon steels (2/0·5/1·25, 3/0·5/1·25, 5/0·5/1·5, per cent.).

Chromium-molybdenum-titanium (5/0·5+titanium).

Chromium-nickel (18-8, 18-8+niobium, 18-8+molybdenum, 25-20, per cent.).

Metallurgy of the Austenitic Nickel-Chromium Steels: Reference Data

H. THIELSCH: 'Physical Metallurgy of Austenitic Stainless Steels.' *Welding Jnl.*, 1950, vol. 29, Dec.; Suppl. pp. 577-621.

This review, prepared under the auspices of the Literature Advisory Committee of the Welding Research Council, is supported by a *bibliography* of 257 references, to published literature and to unpublished communications which have been made to the author specifically for incorporation in the paper.

The various factors which may have a bearing on the characteristics and properties of stainless steels, and, as a result, on their suitability for individual applications, are summarized, with much supporting data.

The first section deals with the *constitution and inherent qualities* of the austenitic steels, and the modification of such qualities resulting from the presence of structures other than austenitic. A table illustrates the relative effect of the various austenite- and ferrite-forming elements which may be present in the austenitic chromium-nickel steels, in comparison with that of the two major elements. Ferrite in these steels is discussed as influenced by temperature, and as affecting properties.

The next section reviews the already considerable literature on *sigma formation*, conditions which produce it (preferential formation from ferrite, presence of alloying elements which favour formation of ferrite, requisite temperature conditions); the occurrence of sigma in castings and in weld deposits; the influence of cold work; rate of formation of sigma; treatments which may be applied for dissolution of this phase, and methods which have been developed for its identification. The distribution of sigma which tends to occur in austenitic steels is also discussed, and the effect of sigma on mechanical and physical properties is illustrated. Information available to date indicates that sigma increases hardness and strength, and considerably lowers ductility and toughness. Adjustment of composition is therefore necessary in some cases, in order to prevent sigma formation between 1050° and 1700°F. (565° and 925°C.).

In connexion with the *influence of carbides*, a distinction is drawn between the corrosion-resisting and the heat-resisting grades of austenitic steel. The well-known phenomenon of intergranular corrosion associated with the precipitation of chromium carbides at the grain boundaries is discussed, and methods for its prevention are summarized: (1) full annealing above 1800°F. (1010°C.) followed by rapid cooling; (2) immunizing heat-treatment between 1350° and 1550°F. (730° and 845°C.); (3) presence of some ferrite; (4) use of the extra-low-carbon grades of steel; (5) use of titanium- or niobium-stabilized grades.

In the heat-resisting grades (most of which contain over 0·20 per cent. carbon) the carbides tend to precipitate within the grains rather than at the boundaries: increase in carbon content is therefore associated with increased hot ductility and enhanced creep resistance. It has also been observed that a relatively high carbon content reduces the tendency of 35-15 nickel-chromium-iron weld metal to cracking. Reference is made to recent electron-microscope studies of the carbides, the outcome of which may further elucidate the influence of these compounds.

Weld-metal cracking in the austenitic steels is of two main types: centreline bead cracks, usually extending from crater cracks, root notches, or entrapped slag, and 'check' cracks, which are generally very fine, and may extend in any direction. Weld-metal cracking can generally be traced to the action of one or more of six major factors: (1) microstructure, (2) composition of the electrode and/or the parent metal, (3) welding technique, (4) the coating of the electrode, (5) the

geometry of the weld, (6) the degree of restraint obtaining during welding. These six variables are reviewed, with examples of their respective effects, and means for preventing unsatisfactory welds are noted.

Susceptibility of austenitic steels to *stress-corrosion cracking* is dependent on several factors, the principal of these being (1) stresses in the steel, (2) the action of the corroding agent, (3) plastic deformation of the steel, (4) the physical and mechanical characteristics of the material, and (5) the length of time for which the material is exposed to the corrodent. In this connexion a review is also made of the effects of composition, including the influence of addition elements, e.g., copper, molybdenum, niobium and titanium. Susceptibility to stress-corrosion cracking may be reduced or eliminated by lowering the crack sensitivity of the steel itself, *or* by heat-treatments which will reduce residual stresses, *or* by adjustment of composition, e.g., by addition of molybdenum.

The austenitic nickel-chromium steels are characterized by higher electrical resistance, lower thermal conductivity and higher thermal expansion than mild steel. They therefore show a greater tendency to *distortion* than is exhibited by the carbon steels or the straight-chromium stainless steels. The implications of these facts, as related to *welding*, are considered in this review, and methods which have been developed for control of shrinkage and prevention of distortion are considered.

Grain size, grain growth and the effects of alloying elements are discussed in relation to the effect of grain on mechanical properties, susceptibility to sigma formation and to intergranular corrosion, and the structure resulting from welding.

The important modifications which may be produced in austenitic steels by *cold working* are dealt with at some length, as influenced by degree, temperature, and rate of deformation, and by composition. Effects of mechanical working are reviewed in relation to the changes produced in mechanical properties, and fabrication operations. *Stress-relieving treatments* discussed include a slight pre-straining of cold-worked material, and stress-relief annealing. Stresses which may be introduced by quenching are considered, and evidence is given indicating that in some cases these are not of sufficient magnitude to warrant stress-removal treatments or to constitute a danger in service. In heat-resistant castings the high hot strength makes the usual stress-relieving treatments relatively ineffective.

The literature dealing with *effects of sub-zero temperatures* on metallic materials shows that the austenitic stainless steels are particularly well adapted for low-temperature service, due to the high degree of austenite stability characteristic of most of the commonly used grades. Only in the metastable steels does sub-zero exposure alone cause transformation into ferrite. It is, however, possible considerably to increase the amount of transformation by prior cold work, or deformation during sub-zero exposure. Effects of sub-zero exposure, with or without straining, are illustrated for typical wrought steels, and the behaviour of castings and of weld deposits at low temperatures is also reviewed. In this connexion it is emphasized that stress-relief and stabilizing heat-treatments appear to have a highly deleterious influence on the sub-zero properties of welds, particularly in the molybdenum-containing grades of steel.

The final section of the paper comprises a review of the *effects of elevated temperatures* on austenitic steels. The information available indicates that for service at high temperatures the use of fully austenitic compositions is generally desirable if maximum hot strength is required. In cases where maximum immunity to the effects of unpredictable stresses is essential the partially ferritic grades may have some advantage. The qualities of ferrite-containing 18-8 weld deposits illustrate the benefits which may, in some cases, accrue from departure from the fully austenitic structure.

Creep strength and stress-rupture properties are improved by the presence of finely distributed particles in the austenite matrix, and structural composition represents the most important factor affecting creep resistance. Effects of niobium, the influence of ferrite, and the effects of carbon content are individually considered, as among the factors determining high-temperature behaviour. A series of tables gives typical values for the high-temperature properties of wrought stainless steels and weld deposits. It is shown that a steel with a coarse grain size will have better creep strength and stress-to-rupture properties than a steel of similar composition, but having smaller grain size.

Production and Fabrication of Stainless Steel: Recent Developments

'Recent Progress in the Production and Fabrication of Stainless Steel.' *Metallurgia*, 1950, vol. 42, Dec., pp. 367-71.

A review article, dealing initially, and at considerable length, with layout and projected operation of the new rolling mills jointly established, for processing of stainless steel, by Firth-Vickers and Samuel Fox and Co., Ltd. A diagram illustrates the building and plant, and the sequence of operations is outlined. It is anticipated that the mills will be in full operation by the end of 1951.

The wide range of stainless steels now in general commercial production is exemplified by reference to the standard Firth-Vickers series, for which typical compositions, relevant specifications, physical and mechanical properties, working characteristics, heat-treatment, and welding properties are tabulated.

Some recent developments in processing of the stainless steels are reviewed, including flame cutting by the flux-injection method, and reference is also made to new Firth-Vickers heat-resisting steels (326, 337, 448 and 467). Brief notes are added on the production of Centrispun castings and the precision casting of stainless steels.

Weld-Decay Resistance of Low-Carbon Nickel-Chromium Austenitic Steels

G. R. BOLSOVER : 'Results of Recent Tests on Resistance to Weld Decay of Low-Carbon Stainless Steels.' *Sheet Metal Industries*, 1951, vol. 28, Jan., pp. 73-6.

The author reports tests made to show the effect of reduction in carbon content on ordinary 18-8 stainless steel, and also compares the behaviour of such steel

(as regards weld-decay resistance) with that of similar steel of somewhat higher carbon content which has been 'stabilized' with titanium.

In the first series of tests comparison was made of the influence of time of re-heating at 650°C., as revealed by the standard acidified copper sulphate test, on five steels of 18-8 type. Three of these were unstabilized, and contained, respectively, 0·08, 0·10 and 0·03 per cent. carbon, while the other two contained 0·06 and 0·05 per cent. carbon, and were stabilized, respectively, with 0·33 and 0·43 per cent. of titanium. As was anticipated, the unstabilized steels containing 0·08 and 0·10 per cent. carbon failed completely in the standard test, whereas the 0·03 per cent. carbon specimen remained free from intergranular attack even after re-heating periods as long as 24 hours. The stabilized steel in which the Ti:C ratio was slightly above 8:1 was also immune from deterioration, but the remaining sample, in which the Ti:C ratio was rather below 5:1, showed some signs of breakdown.

A second series of tests comprised heating of the same steels for 8 hours at 650°C., followed by exposure for times varying from 72 hours to 576 hours, to the standard copper-sulphate solution; later tests comprised similar heat-treatment, but for periods of 16 and 24 hours, followed by exposures up to 576 hours to the corrodent.

Results are individually tabulated, showing data from which the following conclusions are drawn:

Whereas an 18-8 stainless steel, even as low as 0·08 per cent. in carbon content, collapses completely under standard conditions of testing, the 0·03 per cent. 18-8 steel and also the steels of somewhat higher carbon content when treated with titanium, give perfect results so far as resistance to weld decay is concerned. Under the more severe of the test conditions the 0·03 per cent. carbon steel behaves very similarly to the steel having 0·06 per cent. carbon with titanium slightly more than five times the carbon content, but it does not resist weld decay in the accentuated tests quite so well as the steel which contains a Ti:C ratio somewhat in excess of 8:1. It is suggested that the practical conclusion to be drawn is that 'where the standard conditions of testing have proved to be satisfactory as a means of judging ultimate behaviour in service, there is no longer any need for the addition of titanium or any other inhibitor.' Apart from the question of supply of the stabilizing agents, a further point of advantage in the low-carbon steels is that the latter can be manufactured with a high degree of polish which is not satisfactorily obtainable in the titanium-stabilized grades.

The reminder is added that the lower carbon content of the 0·03 per cent. types introduces certain differences in mechanical properties and ductility, which require consideration in assessing the suitability of the low-carbon grades for specific applications.

Cold Working of Nickel-Chromium Stainless Steels

L. F. SPENCER: 'The Cold Working of the Stainless Steels.' *Steel Processing*, 1950, vol. 36, Aug., Sept., Oct., Nov., pp. 383-91, 397, 440-6, 504-8, 570-5, 587.

A practical review of the characteristics of the chromium and nickel-chromium stainless steels governing cold-working technique, with details of procedure which has been proved, by long-term, large-scale experience to be suitable for the respective grades.

The review contains sections relating to the general influence of composition on workability and work-hardening; press operations (shearing, blanking, punching, perforating, bending); forming of curved sections, including draw rolling; forming by the Guérin process; forming of contour sections; shallow and deep drawing; tool materials; lubricants; spinning; cold heading. Types of press used for cutting stainless steels to shape are illustrated, and pressures required for the various operations are discussed. The major literature on cold-forming of stainless steels is referred to in a *bibliography* of 16 items.

Drawing Compounds for Stainless Steel

W. LUEG and A. POMP: 'Drawing Experiments on Alloy Steel Wires under Various Operating Conditions.' *Stahl und Eisen*, 1950, vol. 70, Oct. 26, pp. 977-84.
See also abstract in *Metal Treatment and Drop Forging*, 1951, vol. 18, Jan., pp. 22, 24.

'Carrier' substances which can be used to increase adherence of lubricants to plain steel during drawing operations, e.g., lime, are unsuitable for alloy steels, especially of the high-alloy stainless grades. Metallic coatings, especially lead, have been used for this purpose, and Wohak reported, in 1949, having achieved successful results with coatings of cooking salt. The experiments reported in the present paper were designed to test the efficacy of this method and its practical utility.

Three steels were used: (1) a 1 per cent. carbon steel containing a very small percentage of chromium; (2) a high-speed steel of the chromium-tungsten-vanadium type; and (3) a 0·10 per cent. carbon, 18-8 per cent. chromium-nickel steel. The first two were in the annealed condition, the austenitic steel had been water-quenched.

In the first group of experiments each steel was drawn one pass, the reductions varying from 8 to 47 per cent. In the second group, each wire was drawn four passes, using, as coating, lime alone, or lime and salt, both in combination with soap or grease. The tests were planned to determine also the influence of angle of die, and of rate of drawing, on the power required and work done in drawing. Most of the work was done on the slowly-revolving drum of the double wire-drawing machine in the K.W. Institut für Eisenforschung.

The effect of the salt coating was found to vary somewhat with the angle of the die and the nature of the lubricant used, but the results in general confirmed the utility of the method.

In view of particularly good results obtained with the stainless steel, an additional series of tests was carried out to ascertain the possibility of continuous drawing to large reductions without intermediate annealings. These showed that the lime- and salt-coated steel could be drawn through eight passes (36, 25, 25, 25, 20, 20, 20, 20 per cent. reduction), as compared with the 60 per cent. maximum reduction obtainable in continuous drawing of lime-coated steel wire of the same type. For the first seven draws (down to a

diameter of 1·9 mm.: 86·5 per cent. reduction) the surface remained completely smooth. At that stage, apparently due to exhaustion of the lime-salt coating and resulting cessation of its 'carrier' action, the wire showed grooves. Down to the 6th pass, there was a gradual increase in the tensile strength of the wire; after that stage the increase was much more rapid, and after the 8th pass the value was 206 kg/mm² (92 tons per sq. in.).

From the more general and theoretical angle, the experiments established a number of facts of general interest in connexion with wire drawing: (1) in all instances there was a clear fall in drawing force with increasing speed of drawing, an effect which, it is thought, may be the result of changing conditions of lubrication; (2) the authors' findings are in consonance with the theory held by Sachs, Siebel and others, according to which the drawing force is proportional to the average yield stress of the material and to a complex function of the reduction in area, coefficient of friction, and angle of die; (3) while it is normally believed that the greatest reduction which can be attained in one pass is one for which the drawing force is equal to the breaking strength of the material in question, Lueg and Pomp found that, in the case of the high-speed and stainless steels, for the largest reduction the drawing force was less than 70 per cent. of the breaking strength of the drawn wire, whereas in the high-carbon low-chromium steel no difficulty was found with a reduction for which the drawing force exceeded 85 per cent. of the breaking strength of the drawn wire.

Chemical Analysis of Nickel Alloys

See abstract on p. 28.

Sodium-Hydride Descaling of Nickel-Chromium Resistance Wire

H. C. SMITH: 'Molten Salt Descaling.' *Wire and Wire Products*, 1950, vol. 25, Dec., pp. 1050-1, 1085-9.

Two processes are currently used for descaling of metallic materials by molten-salt treatment: (1) the Dupont, or sodium-hydride process, in which frequent additions of metallic sodium and gaseous hydrogen are made to the caustic soda, and (2) the Hooker or Virgo process, in which an oxidizing salt such as sodium nitrate or permanganate is mixed with the caustic as purchased. The Dupont bath operates at about 700°C., the Hooker process at 800°-1000°C.

This article is concerned with the Hooker method, as used for descaling of nickel-chromium and nickel-chromium-iron alloys and various grades of austenitic nickel-chromium steels, at the works of Wilbur B. Driver Company.

The cycle used is a 15-minute immersion in the descaling bath, followed by a water quench, and subsequent pickling, for 3-5 minutes, in hot muriatic acid, and for an equal time in an unheated nitric-hydrofluoric acid mixture. For some of the high-nickel grades a rather longer time is allowed in the acid pickling bath.

Practical aspects of installation and maintenance are discussed, working procedure is described, and precautions required in operation are reviewed. The process is recommended as being economical and satisfactory; it has been adopted by the Wilbur B. Driver Company as 'an essential and efficient part of the manufacturing process'.

Monel in Pickling Equipment

See abstract on p. 33.

Nickel-containing Materials in the Pulp and Paper Industry

'Construction Materials in the Paper Industry, Part III, Acid Pulping.' *Chemical Engineering*, 1950, vol. 57, Dec., pp. 223-4, 226, 228, 230, 232, 234, 236.

For summary of Parts I and II see *Nickel Bulletin*, 1950, vol. 23, No. 11, p. 218, and 1951, vol. 24, No. 1, p. 24.

In the present instalment the following materials of construction are evaluated for service in acid pulping plant: Worthite, lead, cements, rubber, iron and steel, high-silicon irons, nickel and nickel alloys, Chlorimets, stoneware, Durimet 20.

Worthite. Extensively used in pumps in this section of the paper industry: typical examples are given of the solutions handled.

High-Silicon Irons find no application in the handling of sulphite solutions in the pulp and paper industry.

Nickel and Nickel Alloys. Cooking liquors used for acid pulping may be calcium, magnesium, or ammonium-base bisulphite liquors. Since these liquors involve the use of solutions containing free sulphur dioxide, Monel, nickel, Inconel and Ni-Resist find little application in this connexion. Other materials, especially certain grades of the stainless steels, are to be preferred for such service.

In order to indicate the position of the nickel-containing materials relative to other more suitable types, two tables show (1) plant-corrosion-test results in a collector ring in calcium-bisulphite pumping digester (Types 316, 317 and 309 stainless steels, Inconel, Monel and Ni-Resist); (2) plant-corrosion test in which specimens were attached to the digester cover (Types 316 and 317 stainless steels, Hastelloy C, Worthite, Monel, nickel, Inconel, Ni-Resist, cast iron, mild steel).

The data clearly indicate the greater suitability of the stainless steels for this type of service.

Chlorimet alloys find no application in this branch of the industry.

Durimet 20. The use of this material (complex nickel-chromium steel containing copper and molybdenum) extends throughout the acid plant and digester room. It has been found that in some cases the modified steel will resist successfully conditions which are liable to attack stainless steels of the more conventional types. Pumps and valves form a large proportion of the components for which Durimet is employed in acid pulp plant.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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